Phototransducer for measuring relatively small angles

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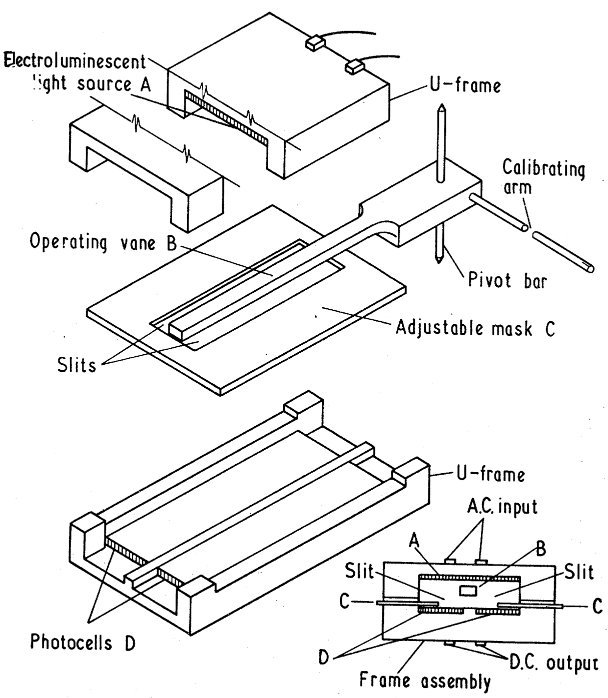
Abstract. A simple, compact and easily applied phototransducer of moderate sensitivity (10^{-4} rad) is described. The design employs two selenium photovoltaic cells connected in a current balancing circuit and an electroluminescent tape. The principle of operation hinges on the differential illuminance of the photocells brought about by the occlusion of the extended light source. A pivoted vane between the light source and photocells is the mechanism that causes the differential shadowing of the cells. Torsion measurements made with recording instrumentation employing this transducer compared favourably with measurements made with a manual apparatus.

There are any number of excellent optical transducers designed for measuring extremely small angles. Hence, in designing this transducer, it was not intended to compete with the sensitivity (10^{-10} rad) of these designs (Jones 1961) but rather to design a simple, compact, easily applied transducer of moderate sensitivity.

Previous to the development of electroluminescent panels, optical transducers were designed around a tungsten filament lamp and it was necessary optically to transform the filament configuration into an extended light source outside the glass envelope. With the advent of electroluminescent panels, an extended light source of great uniformity, reasonable stability and great adaptability can be obtained directly. When electroluminescence is suggested as a light source it is thought that the intensity will be so low as to affect seriously the sensitivity of a transducer. However, the ability of an electroluminescent panel to produce light without heat allows placing of the photosensitive element very close to the light source, thereby increasing the illuminance of the photosensitive surface without any adverse effects due to heat radiation, conduction or atmospheric convection currents. A Sylvania electroluminescent panel (Tape-Lite) with peak spectral response at 510 nm energized with 400 Hz,† 156 v produces a luminance of 14 foot-candles at $\frac{3}{8}$ in. This is more than enough light to generate power in a properly loaded selenium photovoltaic cell with peak response at 560 nm (Sasugo 1960).

The transducer described measures an angle of 10^{-4} rad by using selenium photovoltaic cells connected in a series-aiding circuit with parallel connected meter (Wood 1934), differential optical slits of high aspect ratio (16 : 1) and a relatively large pivoting radius for the operating vane, which forms the common inside boundary for the slits.

Sensitivity was enhanced by increasing the output of the electroluminescent panel and placing it as close as is practical to the photocells and differentially shadowing the photocell areas. Linearity is good because the light flux is a relatively low and constant value (luminance and area of the source remain constant) and the total active area of the photocells remains constant; hence, the algebraic sum of the photocells illumination remains constant. The transducer functions because there is a shift of emphasis of current output from one cell to the other. The electrical factors aiding sensitivity and linearity in the current-balancing circuit of Wood are, first, the low internal resistance of the circuit and, second, the differential character of the circuit.



Exploded and end view of transducer.

The figure shows an exploded view and end view of the transducer that illustrates the relationship of the electroluminescent light source, operating vane, adjustable mask and photocells. The light, mask and photocells were supported within a black light-tight plastic frame consisting of two shallow U-shaped channels which fasten together to form a long shallow box open at both ends. One end of the box was sealed with a light-tight cover; the other end remained open to permit insertion of the operating vane. Precautions must be taken to shield this end from the ambient light. Since electrical output of this transducer is a function of differential occlusion of the cell areas, a transducer signal is generated when the movable operating vane shifts laterally. By the same principle zero setting is obtained by shadowing the outer boundaries of the cells with an adjustable mask. The cells should be carefully matched with respect to current output–area ratio, or in lieu of this a trimming resistor can be connected in series with the photocells to obtain a resistance balance of the circuit. A 0–40 v, 0–0·5 A d.c. constant voltage/constant current power supply was used to adjust the light level of the electroluminescent panel. This power supply energized a 400 Hz oscillator with a step-up output transformer. The regulated power supply effectively isolated the transducer from power line transients. There was a small 800 Hz ripple superimposed on the d.c. output of the photocells which was due to a capacitance effect between the electroluminescent light source and photocells and the rectifying action of the photocells. With a frequency of 400 Hz, a voltage of 156 v a.c. applied to the Tape-Lite and at zero d.c. output of the transducer this 800 Hz ripple amounted to 1·0 mv r.m.s. The transducer signal was fed into an adjustable d.c. amplifier connected between the transducer and recorder. This amplifier had a threefold purpose: firstly, it provided an impedance match between the transducer and recorder (input adjustable from 10 to 1000 Ω; output 10 Ω shunted by a 5000 Ω adjustable potentiometer); secondly, it was the means by which the transducer's mechanical variable was matched to the recorder's scales; thirdly, it filtered out the 800 Hz ripple referred to above (a.c. rejection 60 dB or more above 60 Hz). It was necessary to ground the apparatus to which the transducer was attached to prevent 60 Hz radiated energy from getting into the output signal. It also is important to load the photocell sufficiently; otherwise a time constant can develop which will affect the sensitivity of the transducer.

The signal drift for short periods (10 minutes or less) was negligible. Since the transducer was designed for short term (less than 15 sec) measurements, no study of long term drift was made. Although all electronic components of this instrumentation had good stability, it is unlikely that long term transducer stability could be obtained without regulatory circuitry being incorporated in the transducer design. Both the Tape-Lite and photocells have characteristics that require compensation before long term stability can be realized. A typical Tape-Lite operated at 60 Hz and 120 v increases in brightness after the first 100 hours; from 550 hours on there is a slow steady decrease. At higher frequencies (400 Hz) the time to half brightness for a green Tape-Lite is 1700 hours and to quarter brightness 3600 hours. (This lamp life compares quite favourably with that of a 100 w, 110 v incandescent projection bulb operated under ideal conditions, with only an expected operating life of 100 hours before catastrophic failure.) The output stability of the selenium photocell is a function of load resistance, current density drawn from cell, illumination, temperature, time and manufacturing conditions. It is evident from the above that ageing of both the Tape-Lite and photocells will increase their stability and this proved to be the case. Also Sasugo points out that instability of the photocells due to temperature can be nullified by selecting a low load resistance or by employing a thermistor in the photocell circuit.

The transducer was calibrated with a microscope equipped with a filar micrometer ocular which was used to measure the

† 1 Hz = 1 c/s.

tangential displacement of the calibrating arm (see figure) as it moved in conjunction with the operating vane about their common pivoting centre.

There was an excellent linear relationship (0·4% of full scale) between tangential displacement of the calibrating arm and electrical output of the transducer over the angular range from zero to $2 \cdot 16 \times 10^{-2}$ rad.

This transducer was designed to be used in a torsion measuring apparatus. Its function as part of this apparatus was to detect the small degree of twist in a torsion bar with a very large torsional constant in comparison with the stiffness of samples being tested. The table was prepared from torsion measurement data on eight typical sample materials; note that the maximum difference between transducer and manual data was 4·6%. Since this figure includes other instrument errors plus operator error, it represents a reasonable difference for this type of test.

Comparison of optical transducer and manual instrument performance based on torque measurements

Test material	Torque (g cm deg^{-1}) Trans-ducer	Manual	Dif-ference (%)	Apparent torsional modulus† (lb in^{-2})
White glove leather	2·085	2·184	4·6	500
Side leather	5·530	5·390	2·6	800
Black glove leather	1·110	1·073	3·4	820
Acrylic rubber	16·65	16·80	0·9	1400
PVC–35% DOP	10·44	10·15	2·9	3500
Gasket rubber	23·58	23·45	0·6	4400
Polyethylene	51·00	52·70	3·2	18000
Unplasticized PVC	2825	2850	0·9	476000

† Based on manual measurement.

The particular virtues of this transducer are its simple ruggedness, compactness and ready adaptability, none of which detract from its precision and sensitivity. The 10^{-4} rad it will measure does not represent the ultimate capability of the fundamental design; also it can readily be adapted to measuring small distances. Mechanical dynamic variables in the sonic and supersonic range can be detected since the response time of a photovoltaic cell approaches 2×10^{-5} sec.

References

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